# Orion Pad Abort 1 GN&C Design and Development

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**The first flight test of the Orion Abort Flight Test project is scheduled to launch in Spring 2010. This flight test is known as Pad Abort 1 (PA-1) and it is intended to accomplish a series of flight test objectives, including demonstrating the capability of the Launch Abort System (LAS) to propel the Crew Module (CM) to a safe distance from a launch vehicle during a pad abort. The PA-1 Flight Test Article (FTA) is actively controlled by a guidance, navigation, and control (GN&C) system for much of its flight. The purpose of this paper is to describe the design, development, and analysis of the PA-1 GN&C system. A description of the technical solutions that were developed to meet the challenge of satisfying many competing requirements is presented. A historical perspective of how the Orion LAV compares to the Apollo Launch Escape Vehicle (LEV) design will also be included.**

**The PA-1 LAV consists of a boilerplate CM and a LAS. The solid rocket LAS abort motor propels the LAV during the first few seconds of the abort flight test. The LAS module includes an active Attitude Control Motor (ACM) which is located directly aft of the nose cone assembly. The ACM is a boost-sustain solid rocket motor with eight controllable-thrust nozzles that may be employed to deliver body-axis pitch and yaw torques in response to commands issued by the CM flight control system. The ACM facilitates active, closed-loop, two-axis control of the LAV from abort initiation through LAS jettison. Within the CM are mounted two Space Integrated GPS/INS (SIGI) units that serve as the primary sensors used by GN&C system. The CM also includes the Vehicle Management Computers (VMC) that host the GN&C flight software.**

**One of the major differences between the Apollo and the Orion launch abort systems is the aerodynamic stability of the configurations. Although the overall launch abort configurations are very similar, the location of the Apollo center of gravity and the addition of ballast to the Apollo launch escape tower resulted in a configuration that was statically stable. With the location of the Orion center of gravity, a ballast of over 2000 pounds would be required to obtain a static stability margin comparable to that of the Apollo configuration. Because of the launch vehicle constraints, the program decided this was an unacceptable approach. This resulted in the requirement for an active control system during the abort maneuver and led to the development of the attitude control motor which is located at the top of the LAS.**

**Much like an actual Orion LAS abort, the PA-1 mission profile involves transitioning through a series of phases. An initial pitch-over maneuver is performed, which is followed by a velocity commanded guidance mode which ensures that the vehicle reaches a safe downrange distance from the launch pad. At the appropriate flight condition, the vehicle reorients to a heat-shield-forward attitude, finally settling to a commanded trim condition for Crew Module jettison. After reorientation, the autopilot damps out rate oscillations in preparation for Crew Module jettison. The LAS and CM separate through activation of the retention and release mechanism and Jettison Motor and the CM remains without active**

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**attitude control for the remainder of the test. The Drogue and Main Parachute systems are deployed using time based sequencing to stabilize the vehicle and control descent rate until touchdown.**

**The complexity of the pad abort mission timeline presents a unique challenge in designing the nominal flight profile. The goal is to use the energy provided by the abort motor in the most efficient way to maximize downrange, or distance from the crew hazard, while providing enough time, or altitude, to perform key mission transitions (these include re-orientation, LAS jettison, and drogue/chute staging). The design of the trajectory and timeline for the PA-1 flight test is driven by many competing requirements. Nominal trajectory design starts by collecting all of the program requirements that affect flight performance. The requirements are then converted into a set of flight constraints that the trajectory must satisfy. The trajectory is then shaped using a standard optimization process where the objective is to maximize downrange at touchdown while meeting all imposed constraints (reference trajectory design is performed in a 3-DOF simulation). Because most of the requirements must be met with a 3-sigma probability, the reference trajectory is verified by performing a quick Monte-Carlo validation in a 6-DOF simulation, using the actual flight controller. If the trajectory is violating any requirements, further refinement of the reference trajectory must be performed. Once a baseline trajectory is calculated, GN&C algorithms are modified to ensure that the nominal 6-DOF trajectory matches the reference trajectory as close as possible. The final step is to verify the new GN&C system through closed-loop full 6-DOF Monte-Carlo simulation.**

**The PA-1 navigation algorithm processes the data from the FT-SIGI units into position, velocity, attitude, and attitude rate data that is used by the guidance and control algorithms. During the initial pitch-over phase of the abort flight test, the PA-1 guidance algorithm produces open-loop commands intended to follow the established reference trajectory. Following the initial pitch-over maneuver, the guidance algorithm transitions to a downrange guidance mode that modulates the angle of attack command to track the velocity profile for the desired trajectory. During reorientation, angle of attack and angle of sideslip commands are generated to reorient the vehicle in preparation for the jettison of the LAS. All commands are sent from the guidance algorithm to the control algorithm in the form of a commanded attitude quaternion. The LAV flight control algorithm employs a classical, Proportional-Integral-Derivative (PID) topology to track guidance commands in either inertial pitch and yaw attitude or angle of attack and sideslip. Feedback control gains are computed onboard according to a simplified partial dynamic inversion approach. Bending filters are used to filter SIGI measurements before being used for feedback control. Because of airframe roll-yaw cross-coupling associated with the off-axis location of the CM center of mass, the ACM may also be used to provide a limited amount of roll rate stabilization. The robustness of the flight control algorithms is evaluated using linearized stability analysis.**

**The PA-1 GN&C subsystem level requirements verification is conducted through use of two independent high-fidelity 6-DOF simulations. Output datasets are analyzed from large monte-carlo simulation sets to evaluate subsystem performance and categorize margins with respect to the requirement allocations. Sensitivities are analyzed using statistical methods to determine performance margins to input dispersion parameters and clustering analysis. Control system and navigation system performance are individually evaluated to isolate the contributions of each to the total system performance. The trajectory of multiple bodies is tracked to provide assessment of the separation distance and landing footprints for range safety requirements.**